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DAMAGE TO TREES AND REGENERATION LAYER RESULTING FROM TIMBER HARVESTING WITH THE USE OF EQUIPMENT AGGREGATED WITH FARM TRACTORS IN THINNED MOUNTAIN STANDS

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Abstact: *The aim of the present research was to examine the influence exerted on the forest environment by some selected manual-machine thinning technologies through determination of the levels of damage to trees remaining on stem and to the regeneration layer.*
The research was located in fir and spruce stands in Gorlice Forest District, Gromnik FD and Nowy Targ FD (the Regional Directorate of the State Forests in Kraków), where early selection thinning was performed with the use of debranching and cutting processor NIAB 5-15 along with a cable winches TUN 40 and KRPAN 8 EH, aggregated with farm tractors. In the case of the harvesting with the use of the processor, the level of damage to trees was 1.0–5.2% while with the use of winches it was 1.2–5.4%. In the regeneration layer, the level of damage when the processor was used ranged from 5.9–17.9% whereas harvesting with the winches caused damage between 11.8 and 17.1%.

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1. Introduction, aim and scope of the study

Farm tractors constitute the largest (over 4,600) group of machines used for timber skidding in Poland (Zastocki, 2001; Kocel, 2005). As the tractors are utterly ill-adapted to difficult transporting operations, they increasingly rarely skid timber by hauling. The contemporarily encountered machines are aggregated with various devices, e.g. cable winches, self-loading trailers with hydraulic cranes as well as debranching and cutting processors. Due to the application of such devices, farm tractors are not only enabled to skid and forward, but they also reduce the logger's workload in debranching and cutting when applying the processors. Such devices have already been used in Scandinavia, Western Europe and Northern America in mid eighties of the previous century (Richardson, 1987; Moberg et al., 1988; Marntell and Marntell, 1989; Roderick, 1994, 1995), predominantly for tree logging purposes on a small scale in private forests. The first mention in the Polish literature dates back to mid nineties (Giefing, 1994a, 1994b; Walczyk, 1997). It was only ten years later, however, that the first such processor NIAB 5–15 was imported to Poland and applied on the territory of the Regional Directorate of the State Forests in Kraków. As indicated by Lindroos et al. (2005), over 150 processors installed on farm tractors were sold in Sweden for forest works only in the year 2002. Probably merely about 10 of such machines are used for thinning purposes in Poland nowadays.

Applying processors in tree logging is considered to be one of the less harmful technologies for the stands. According to the Swedish researchers (Marntell and Marntell, 1988), tree damage with the use of

VIMEK G30 processor technology oscillated at the level of 1.1–4.8%. In the recent years, some analyses (Sowa et al., 2007; Moskalik, 2008) regarding, among others, applying processors in the Polish forests, appeared in the subject matter literature. Nevertheless, they mostly refer to economic aspects of the topic. Therefore, the aim of this study was describing the scope and character of damage arising on the trees and regeneration layer remaining in the stands of younger age classes, after thinning with technologies at the manual–machine level in the Polish stands and field conditions. The scope of research comprised the comparison (from the ecological perspective) of two work technologies: the one involving the use of the processors and the other applying cable winches, commonly used in the Polish forests. The research was carried out on the mountain spruce stands (*Picea abies* L.) as well as fir stands (*Abies alba* L.) subjected to early thinning.

2. Methods

2.1 Research location

The research was located in the Gorlice, Gromnik and the Nowy Targ Forest Districts, which are part of the Regional Directorate of State Forests in Kraków, and where selective early thinning was arranged. Twelve sample plots were set up in the designated stands in total. Harvesting by means of NIAB 5–15 processor with cyclical debarking as well as KRPAN 8 EH cable winch was performed in the spruce stands of the Nowy Targ forest district (6 plots). On the other hand, harvesting with the application of the processor and the TUN 40 cable winch was performed in the area of the two neighbouring Forest Districts: Gromnik (3 plots) and Gorlice (3 plots). Thinning was performed in high vegetation season. The overall characteristics of the stands with sample plots are presented in Table 1.

Table 1. Characteristic of stands in sample plot

Forest district Compart-ment	Techno-logy	Area [ha]	Stand composition	Age [years]	Index of stocking	Growing stock [m^3/ha]	Slope [%]	Forest site type
Nowy Targ 245b (2 plots)	NIAB 5-15	12.95	spruce (fir)	45	1.1	320	13-17	Mixed mountain broadleaved forest
Nowy Targ 253d (1 plot)		4.58	spruce (fir)	35	0.8	90	13-17	Mixed mountain broadleaved forest
Nowy Targ 245c (3 plots)	KRPAN 8 EH	9.19	spruce (fir)	25	1.0	50	8-12	Mixed mountain broadleaved forest
Gromnik 307a (3 plots)	NIAB 5-15	10.65	fir (beech)	39	0.9	164	18-30	Upland broadleaved forest
Gorlice 45b (1 plot)	TUN 40	26.01	fir (beech, larch)	49	1.1	254	13-17	Fresh mountain broadleaved forest
Gorlice 48a (2 plots)		30.46	fir (sycamore, ash)	55	1.0	351	8-12	Fresh mountain broadleaved forest

In order to determine the influence of the harvesting process on the existing regeneration level and on the remaining stand, research was done in two stages. In the first stage, in randomly selected fragments of stands, a network of squares with the side length of 12.5 m was established on manipulation plots of 0.5 ha. At the nodes of the network 0.5–are circular plots with a radius of 3.99 m were located (altogether 32% of each manipulation plot area). Before felling, the tree and regeneration layer stock-taking was performed. The group of trees included all specimens with the breast-height diameter of over 7 cm. The regeneration layer included juveniles aged over 2 years, consisting of saplings of the main forest-creating and admixture species, whose breast-height diameter was below 7 cm. The species of bushes were disregarded. The field work resulted in setting up to 12 manipulation plots and permanent marking of 384 circular plots on which over 3,500 trees and almost 1,700 saplings in the regeneration layer were inventoried.

In the second stage, directly after the thinning was completed, the size and quality of damage to trees and to the young generation were determined. The trees which remained after the thinning, and which had been damaged, underwent measurements of the height of location of the injuries on stems and measurements of their linear dimensions (vertically-length, horizontally-width). The parameters of damage situated at the height over 2 m were estimated visually. Moreover, the location of the damage was noted considering the roots, the root neck and the remaining part of the stem. Damage done to the regeneration layer was classified according to the damage classification which has been used in the Department for a few years and which is presented in Table 2 (Sowa and Stańczykiewicz, 2005, 2007; Stańczykiewicz, 2006). Additionally, it was assumed that the whole regeneration layer has utility value from the perspective of forest cultivation.

Table 2. Classification of regeneration damage

Damage class	Characteristic of damage
I	destroyed or disappeared tree
II	damaged tree, will not survive
III 1	broken top sprout above the last whorl
III 2	broken bolt below the last whorl
III a	broken side-branches (up to 20% of total amount)
III b	broken side-branches (21 - 40% of total amount)
III c	broken side-branches (above 40% of total amount)
IV	tree out of plumb
V	torn off bark

2.2. Harvesting system

In case of the surfaces on which the processor was working, the role of the chain saw operator was reduced to cutting and felling trees. Debarking and cross-cutting was performed by a processor located on the skidding routes (Fig. 1). The obtained basic material in the form of the middle-sized timber logs, was situated in irregular piles, directly by the routes from which it was then skid by means of self-loading trailers. Therefore, the described technology could be qualified within the framework of Cut-To-Length method ($CTL_{TractorProcessor}$) with two-stage skidding.

Figure 1. Tractorprocessor NIAB 5-15
(www.forsmw.com)

Figure 2. Cable winch KRPAN 8EH
(phot. A. Stanczykiewicz)

In case of technologies with cable winches the logger's task, apart from felling a tree, was also debranching and cross-cutting the material. After cutting off the tree top, the whole-length trees were skid to the skidding route by cable hauling, after which they were transported to upper landing by skidding after leaning tree-stumps against the winch plate (Fig. 2). Such procedure can be qualified as Tree-Length-System ($TLS_{CableWinch}$) (Pulkki, 2004). Manipulation plot areas were set up in such a way that the maximum logging distance of the skidding in the first stage would not exceed 50 m. During the logging, forest workers did not use any means, such as self-clenching, openwork skidding tongs or cross tree fenders leaning against tree stems, which could protect the trees and the regeneration layer remaining in the stand. One of the basic methods of preventing damage was maintaining the direction of felling trees possibly similar to the direction of the subsequent skidding to skidding routes by means of a cable.

2.3. Calculation methods

It was assumed that the area of damage due to timber harvesting would be calculated using formulas for the field of an ellipsis or a rectangle, depending on the shape of the damage (Butora and Schwager, 1986). Due to the varied numbers of saplings on the sample plots, the amount of damage and destruction in the regeneration layer was presented as percentage value. The percentage of losses in particular damage groups was calculated in relation to the number of trees inventoried before the thinning.

In the case of analysis of the influence of the technologies applied on the tree and the regeneration levels, hypotheses H_0 of the accordance of empirical distributions with the normal distribution were made for the following random variables:

- the percentage of damaged trees,
- area of injuries made on trees which remained in the stand after the thinning,
- the height of location of injuries on tree stems,
- the percentage of damaged saplings in the regeneration level.

Statistical verification of the above hypotheses H_0 was based on the Shapiro-Wilk test.

In order to determine the significance of differences between the level of damage to the trees and the regeneration level, and their damage injury area as well as its location height, the following hypothesis was made: H_0 – the average values of the percentage of damage in the regeneration level and the tree level as well as the injury area and its location height on stems are equal (at a significance level α=0.05). It was assumed that in the case of accordance of empirical distributions with the normal distribution, the H_0 would be verified using the t-Student test. In the case of the lack of such accordance, the U-Mann-Whitney test would be applied.

3. Research results

The results of the Shapiro-Wilk test did not show accordance with empirical distributions with the normal distribution for any of the random variables analysed. That is why, in order to determine the differences between the average values of the empirical distributions under analysis, the non-parametric U-Mann-Whitney test was applied.

3.1. Tree damage

As a result of field work and statistical analyses performed, it was noted that on the manipulation plots where harvesting was carried out using the technology with the NIAB processor, damage was done to the total amount of 3.6% (1.0–5.2%) of the trees which remained on stem after thinning. On the other hand, the thinning on the plots where the technology with the use of cable winches was applied, resulted in damage to 2.6% (1.2–5.4%) of trees. The results of the U-Mann-Whitney test made the authors accept the H_0 concerning the equal values of the average percentages of damage in the tree layer (Z_{emp}=0.262; p=0.793). In this regard, considering all manipulation plots, the conclusion is that the difference between the average level of damage to trees in both technologies is not significant. Table 3 presents the percentage of damaged trees in relation to the kind of stands and technologies.

Table 3. Percentage of damaged trees [%]

Technology \ Stands	Common silver fir	Norway spruce
CTL_{TP}	2.5	4.4
TLS_{CW}	4.6	1.8

The results of analyses concerning the comparison of the injury areas allow for a conclusion that in the trees damaged in the TLS_{CW} technology, the size of injuries was smaller (67 cm^2on average) in comparison with the injuries created as a result of CTL_{TP} technology (101 cm^2on average). The differences to the disadvantage of the processor (Table 4) are statistically significant at the probability level p=0.000 (Z_{emp}=3.920).
The analysis of the height of the location of injuries allowed for a conclusion that, on the plots where the TLS_{CW} technology had been used, injuries on the tree stems were located higher (on average at 0.71m) than on the pots where CTL_{TP} technology had been used (on average at 0.31m). The U-test results (Table 4) indicate that there is a significant difference between the height of the location of the injuries on the stems of the injured trees (Z_{emp}=-2.825; p=0.005).

Table 4. Results of Mann-Whitney U test of significance of difference between tested variables

	Technology of timber harvesting		**Variable**	**Median**	Z_{emp}	p	H_0
All stands	processor[A] / cablewinch[B]	injury	area [cm^2]	66[A] / 24[B]	3.920	0.000	–
			height [m]	0.22[A] / 0.41[B]	-2.825	0.005	–
Common fir stands			area	60 / 14	2.940	0.003	–
			height	0.36 / 0.55	-1.922	0.045	–
Norway spruce stands			area	71 / 42	1.999	0.046	–
			height	0.18 / 0.16	-0.778	0.437	+

Symbols: Z_{emp} – normal distribution statistics, p – statistic probability, H_0 – zero hypothesis (+ accept; – reject)

3.2. The regeneration layer damage

In the case of damage due to harvesting to the regeneration layer presented in Table 5, it can be noticed that the percentage of damaged and injured saplings in all stands was higher on manipulation plots where harvesting with the use of winches had been applied. However, the results of the analysis of the significance of differences (Z_{emp}=-0.841; p=0.400) do not provide the basis for the rejection of the hypothesis concerning the equal average values of the share of damage in the regeneration layer. These result point to the identical level of damage to the regeneration layer as a result of application of both technologies. Considering the percentage of damage in the damage classes, the highest share was noted in class I: destroyed and missing saplings (from 5.8 to 14.9% in TLS_{CW} and from 4.4 to 7.6% in CTL_{TP}) and in class V saplings with bark torn off (from 0.5 to 4.1% in TLS_{CW} and from 2.3 to 2.5% in CTL_{TP}). The share of saplings out of plumb is also significant: third in relation to the amount of damage.

Table 5. Percentage of damages in regeneration layer [%]

Technology of timber harvesting		**Damage class**									**Total**
		I	II	III 1	III 2	III a	III b	III c	IV	V	
All stands	CTL_{TP}	**4.7**	-	0.2	0.4	0.1	0.1	-	1.0	**2.3**	8.9
	TLS_{CW}	**10.2**	-	0.2	0.5	0.3	-	-	0.9	**2.4**	14.5
Common fir stands	CTL_{TP}	**4.4**	-	0.3	0.4	0.1	0.1	-	0.7	**2.3**	8.4
	TLS_{CW}	**5.8**	-	0.4	0.9	0.6	-	-	1.3	**4.1**	13.2
Norway spruce stands	CTL_{TP}	**7.6**	-	-	-	-	-	-	3.8	**2.5**	13.9
	TLS_{CW}	**14.9**	-	-	-	-	-	-	0.5	**0.5**	15.9

5. Discussion

The level of tree damage shown in the study, both on the plots where the winch and the processors had been used, should be considered satisfying, as it does not exceed the level of 5% - the level which is slightly arbitrarily assumed and not everyplace used in the Polish conditions. The earlier research of the early pine stand thinning carried out by Sowa and Stańczykiewicz (2007) with the identical method showed that 3% of trees were damaged with the thinning technology of the light cable winch powered by a chainsaw engine with the towing power of 1 ton. The horse skidding technology compared in this study caused damage to circa 4.5% of trees. The following question arises when analysing research results: why was the damage level in case of the technology with the use of the processor higher than in case of the technology with the use of the cable winch? According to the Swedish research (Marntell and Marntell, 1988), damage in the early spruce stand thinning did not exceed 5% (from 1.1 to 4.8%). On the other hand, the Canadians (Richardson, 1987; Roderick, 1994, 1995), carrying out research with the use of three models of processors, report that the damage level as a result of felling trees and skidding timber was below 3%. It seems that one of the reasons for the higher damage level stated in this study was felling trees in directions which were different from the direction of the subsequent skidding. As a consequence, the skidded material in the form of the whole trees with tree-tops caused damage at a stage of arranging in the skidding direction behind the hauling cable; and in the thicker fragments of the manipulation plots the big tree branches damaged trees growing in the closest neighbourhood. In the case of skidding timber delimbed by a logger in cable winch technology, the load of a smaller volume would move between the remaining trees more easily, causing less damage at the same time. Detailed analyses carried out within the framework of the mentioned research did not ascertain, contrary to this study, the influence of the applied harvesting technologies upon the size and the location of injuries.

The analysis of injuries' distribution on the stems of all trees damaged as a result of applying both technologies showed that about half of them (45.4–64.2%) occurred on roots and the root neck (Fig. 3). The obtained results confirm the earlier research. As shown in the diagram presented by Butora and Schwager (1989) concerning the distribution of injuries on the stem, almost 55% of injuries occur on the roots and the root neck up to 0.3 m. The greater share of the injuries in the lower spruce stands results from the morphological construction of the spruce with a large number of roots growing shallow in the soil and protruding from it. Analogical outcomes were achieved in the research by Sowa and Stańczykiewicz (2007), in which over 2/3 of the lowest injuries (68.4–75.9%) were noted in the spruce stands, both as a result of using horse skidding technology and the light Multi FKS cable winch powered by the chainsaw engine. In the quoted research the average areas of injuries oscillated at the level from 62 cm2 with the use of the light cable winch to 68 cm^2 with the use of horses, and they were located at the height from 0.26 m to 0.40 m.

The analysis of Table 5 shows that the percentage of the destroyed and damaged saplings in the group of all stands oscillated at the level of 9–15%. Similar results were achieved in the earlier research by Sowa and Stańczykiewicz (2005, 2007), in which the calculated levels of destruction and damage reached the level of 10–15% of the total number of saplings in the regeneration level. It seems that such level of damage should be considered high and potentially influencing further growth of the regeneration level in the negative way. However, a univocal answer to the question about what influence upon presented level of the stand the damage may have, requires long-term, repeatable study of the stand development on the previously set up permanent sample plots. The analysis of damage taking into consideration the damage classes allowed to notice that a very similar injuries classification was described by Granhus and Fjeld (2000), whose study distinguished four classes of saplings damage. The first one includes destroyed or missing saplings, the second one: saplings with injuries in bark and wood, the third one: saplings out of plumb and the fourth one: saplings with broken parts. A similar structure of damage resulted from the research by Korten and Pausch (2000) who noticed the highest number of destroyed or missing saplings (over 2/3 of the whole group of damaged saplings). The lowest damage level was noticed in the case of saplings with broken parts. It was also in this study that damage least often occurring broken parts (the total share of the damaged saplings oscillated within 0.8–1.9%).

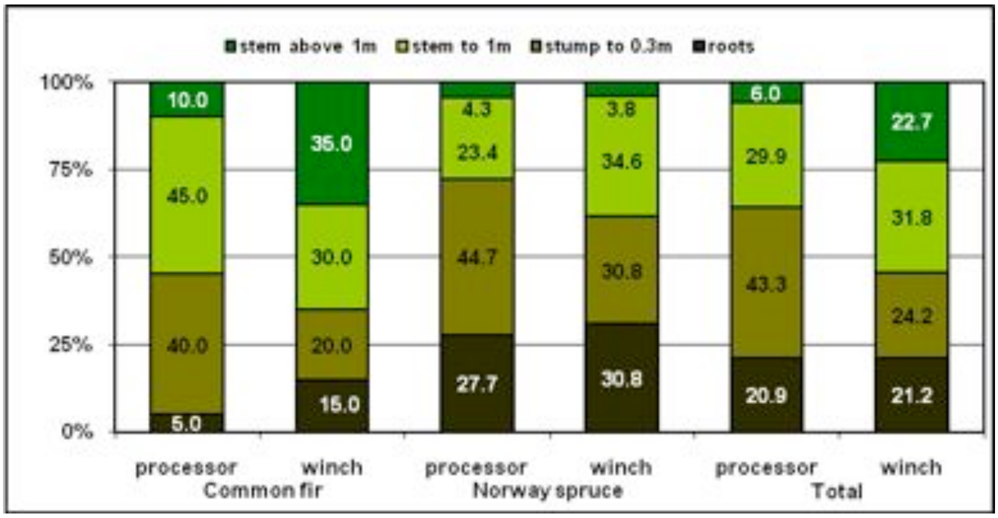

Figure 3. Distribution of injuries on trees

5. Observations and conclusions

1. The application of the harvesting technology with the processor (CTL_{TP}) resulted in damaging more trees as compared with the TLS_{CW} technology using cable winches. Detailed analyses showed that the difference between the damage level of those two technologies is not significant.
2. The average area of injuries created as a result of using TLS_{CW} technology was smaller than the area of injuries caused by timber harvesting in CTL_{TP} technology. Both in spruce and fir stands the difference occurred to be significant.
3. In most cases the analyses confirmed the influence of the applied technology upon the location of injuries. Taking into consideration all stands, it was stated that injuries significantly higher located were the injuries made during harvesting with cable winch technology.
4. The study outcomes point to the fact that about half of all injuries made on trees which remain on stand was made on the roots and the root neck up to 0.3 m, and most injuries were located up to the height of 1 m, that is in the higher risk zone of the subsequent depreciation of the most precious, tree-stump timber, especially in the spruce stand.
5. As a result of the application of two different manual-machine technologies of harvesting, the performed cuttings resulted in significant damage in the regeneration layer. The damage level in technology with the use of the processor was close to 10%, and with the use of the cable winch – close to 15%. However, the analyses point out that those values are not significantly different.
6. The analysis of the kinds of damage done to the regeneration level shows that tree felling and skidding most often caused damage in the form of sapling destruction or tearing off bark as well as moving out of plumb.
7. From the ecological point of view, the thinning technology with the use of both cable winch (TLS_{CW}) and the processor (CTL_{TP}) can be recommended for practical application as the ones which exert little negative influence, mostly on the trees remaining in stands after the thinning.

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